Replication Middleware for a Tactical Mobile Wireless Environment

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Workshop on 'Data Replication over Disadvantaged Tactical Communication Links'

- Organized by IST RTG-012
- Hosted by DRDC Valcartier
  - Quebec City, 11-12 September 2002
- 23 participants from 7 countries
- http://www.valcartier.drdc-rddc.gc.ca/tgonimdg/
- This presentation presents summary of some of results from Data Replication Workshop

What is Data Replication ?

- Systematic propagation and maintenance of copies of data between datastores within a distributed environment

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Why Replicate Data in the Tactical Domain ?

‘Network-Centric Warfare’

- ‘An information-superiority enabled concept of operations that generates increased combat power by networking sensors, decision makers and shooters to achieve:
  - shared awareness
  - increased speed of command
  - higher tempo of operations
  - greater lethality
  - increased survivability
  - a degree of self-synchronization

D.S. Alberts, J.J. Garstka, F.P. Stein, ‘Network centric warfare: developing and leveraging information superiority’, CCRP Publication Series, 1999

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Tactical Communications Constraints

- Units are highly mobile
- Communicate by radio (voice and data; voice only; data only)
  - shared (broadcast) medium
  - connectionless
- Low data throughput (< 1 kbit/second for CNR(P))
- Variable data throughput
  - highly dependent upon traffic load on communications network
- Unreliable links (frequent disconnection, high bit error rates)

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Data Distribution Requirements in Tactical Wireless Domain

- Autonomous cooperating nodes
  - disconnected operation
- Peer-to-peer model (not client-server)
  - avoid single point of failure
- Propagate updates asynchronously on ‘all-informed’ basis
  - profit from (shared) broadcast medium
  - change role without substantial one-time data transfer
  - recover data from any node
- Data recovery must be carefully managed (bandwidth issue)
- Data ownership an important issue (integrity and bandwidth)
  - single ownership of data to avoid/minimize data conflicts
- Negative acknowledgement scheme

Desirable Characteristics of Replication for Tactical Wireless Domain

- Network Topology – peer-to-peer
  - avoid single point of failure

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Synchronous vs Asynchronous Replication

- ***Synchronous*** replication provides ‘tight consistency’ between data stores through two-phase commit protocol (update to originating and replicate database occurs at same time)
  - requires high network availability and bandwidth
  - not practical in tactical wireless domain
- ***Asynchronous*** replication provides ‘loose consistency’ between data stores.
  - There is latency before data consistency is achieved because replication occurs some time after originating transaction.
  - used in tactical wireless domain

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Desirable Characteristics of Replication for Tactical Wireless Domain

- Asynchronous Replication
  - most commercial replication mechanisms support tight consistency, or loose consistency but assume latency not an issue
  - in reality, ‘loose consistency’ often not achievable in tactical wireless domain
  - due to low & variable throughput of tactical comms network, some replicated data may not reach its destination
  - must live with a state of ‘lazy consistency’, in which the datastores never fully synchronize and it is always the case that, at any given time, some data values will be inconsistent.
  - mechanism should protect consistency of high-value information when network performance degrades (graceful degradation)
- Propagation of database changes
  - bandwidth-efficient when replicate only values that have changed

Asynchronous Replication – communication types

- Database-to-database
  - collect process : select data to share from primary data source
  - distribution process : deliver replication package to targets
  - apply process : apply database changes at target
  - implemented as middleware, high application transparency, preserves transactional integrity
- Process-to-process (publish/subscribe messaging)
  - publish process (part of originating event)
  - distribution process (usually store-and-forward)
  - subscribe process (interested processes receive message)
  - apply process (in accord with pre-defined business rules)
  - implemented as middleware with simple APIs (not application transparent), preserves transactional integrity

Data Ownership Models for Asynchronous Replication

- **Master/Slave**
  - each individual data element has only one ‘owner’ (primary source) with the right to modify the data value
  - modified value replicated to target replicas, and applied
  - facilitates data reconciliation and recovery
- **Update-Anywhere** (aka peer-to-peer or symmetric replication)
  - no designated master (primary source) for data element
  - any participating data store can modify the element’s value and replicate the change to other data stores, where it is applied
  - difficult to track author of data change; enables data conflicts
- **Hybrid (Two-Way Master-Slave)**
  - each participating data store acts as ‘owner’ (primary source) for a subset of total data set; is primary source (sender) for certain data changes and target (recipient) for other changes

Desirable Characteristics of Replication for Tactical Wireless Domain - Summary

- Peer-to-peer network model
- Broadcast protocol (connectionless)
- Asynchronous replication
  - enforcing ‘lazy consistency’
    - graceful degradation protecting consistency of high-value data
  - database-to-database communication
  - propagate only what has changed
  - two-way master-slave data ownership model

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Army Tactical Command Control and Information System (ATCCIS) Background

- ATCCIS Objectives
  - 16 NATO nations
  - Interoperability between C2ISs
  - Software/Hardware/Vendor-independent Solution
  - Two Main Products: Common Data Model and ARM (ATCCIS Replication Mechanism) specification
  - Database-to-Database Replication
- MIP (Multilateral Interoperability Programme)
  - Goal: To Field an Interoperability Solution
  - Adopted ATCCIS Products
  - Merged with ATCCIS in 2002

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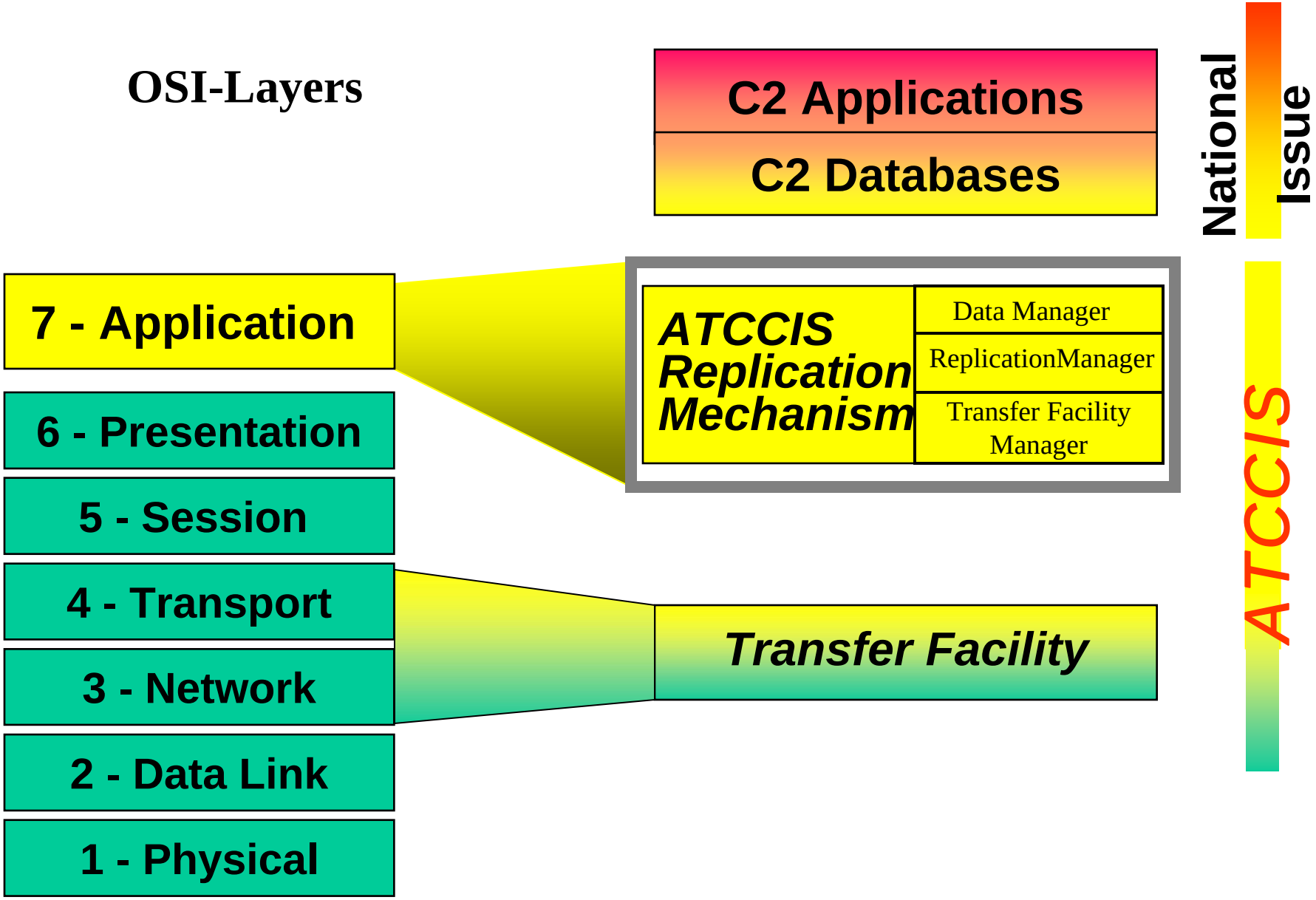
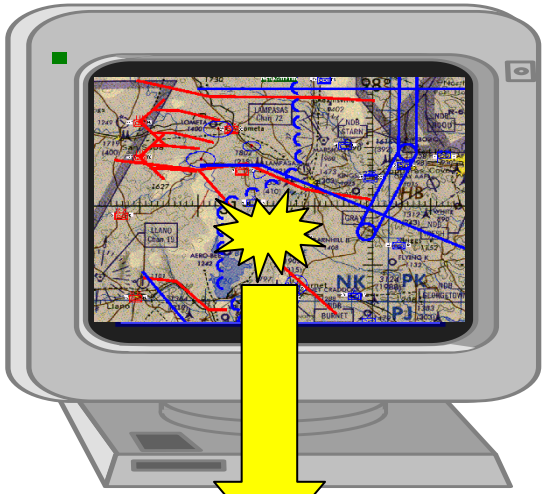
ATCCIS and OSI Layers



ATCCIS Concept of Operation



National C2 System
Processing and Presentation

National Database

Physical Data Storage

Conceptual Data Model

Standard Data Definitions

ATCCIS Replication Mechanism

Common Replication Architecture

Data Transfer Protocols

Communications Link

ATCCIS Replication

- Replication Contracts
  - "Negotiated Push"
  - Agreement by both Parties -> Automated Exchange
- Filters
  - On Data Value and Data Source, Simple and Complex
- Payload Reduction
  - Reference Data + Transmission Efficiency Rules
- Replication Messages
  - Incremental Update (new/changed data only)
  - Bulk Update (for synchronization)
  - Control Messages (e.g. activate node, propose contract)

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Desirable Characteristics of Replication for Tactical Wireless Domain - Summary

	ARM
• Peer-to-peer network model	YES
• Broadcast protocol (connectionless)	NO
• Asynchronous replication	YES
– enforcing ‘lazy consistency’	NO
• graceful degradation	NO
– database-to-database communication	YES
– propagate only what has changed	YES
– two-way master-slave data ownership model	YES

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What is Missing ?

- In the tactical wireless domain, for optimum performance the replication protocol must be able to sense, and adapt its behaviour to, the constantly varying state of the communications network
- A Replication Transport Layer must be installed that sits between the Replication Mechanism and the network layers
- The Replication Transport Layer should
  - take advantage of shared medium
  - use a standard connectionless transport layer (UDP not TCP)
  - sense and adapt to varying state of comms network

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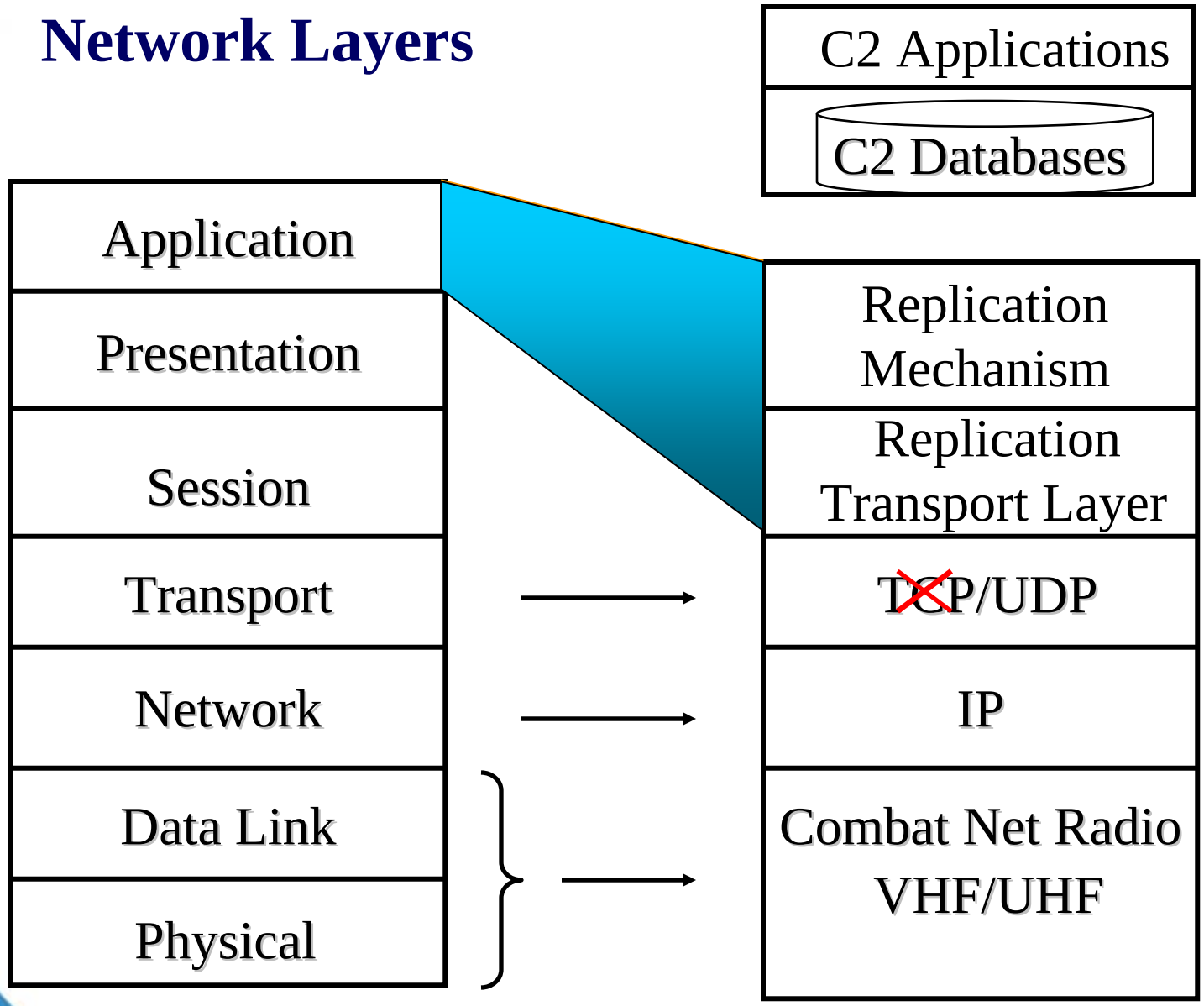
Network Layers



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Functional Requirements for Replication Mechanism and Replication Transport Layer

- Replication Mechanism (RM) must
  - determine when replication is to occur (context-sensitive)
  - determine what is to be replicated
  - assemble the replication Protocol Data Unit (PDU)
  - apply received PDUs
- Replication Transport Layer (RTL) must support
  - prioritization at PDU level (sensitive to time-varying network state)
  - retransmission protocol (sensitive to time-varying network state)
  - degree of fault tolerance
  - fragmentation/defragmentation of PDUs
  - acknowledgement scheme (negative ACK)

Functional Requirements Delivered by Combination of RM and RTL

- Determine level of effort allocated to PDU Tx
  - based on importance of PDU content
    - number of retransmission attempts
    - choice of class of transport service (guaranteed, best effort)
- Track and enforce data ownership
  - authority structure for management of database keys
- Mediate dependencies on other system components
  - dependency of RM on characteristics of a particular DBMS
  - dependency of RTL on characteristics of particular DM or RM

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Conclusions

- In the tactical domain, data replication is key to shared situational awareness
- To be effective in this domain, replication mechanism and protocols must be capable of sensing and adapting to the changing state of the communications network
- Commercial replication mechanisms support ‘tight consistency’, or ‘loose consistency’ but assume latency (time to resynchronize) not an issue
- No replication mechanism developed to date has proven fully effective in the tactical military domain


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